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SEISMIC HAZARD ZONATION MAPPING AT THE NATIONAL SCALE

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I. Objective and Policies

This paper presents the basic elements of ongoing research programs to produce probabilistic earthquake ground shaking hazard maps on national and regional scales (i.e., 1:7,500,000 to 1: 250,000) and, in cooperation with other Federal, state, and local government agencies and professional organizations, to disseminate them and foster their use. The goal is applications on national, regional, and urban scales (e.g., 1:24,000 or larger) that will protect lives and property and reduce losses from earthquakes.

The primary applications are regulations for new buildings, rehabilitation of existing buildings, standards for siting and design of lifelines, risk assessments, loss estimates, model building codes, seismic zonation (i.e., the scientific process of identifying those parts of an urban area which are best and least suited for community development in terms of their exposure to an earthquake hazard), and other applications in the framework of the disaster reduction planning cycle (i.e., mitigation, preparedness, emergency response, and recovery and reconstruction). Such maps were mandated in the "Earthquake Hazards Reduction Act of 1977" (Public Law 95-124) and subsequent amendments.

The enactment of the "Earthquake Hazards Reduction Act of 1977" (which hereafter will be referred to as the Act) represented the culmination of parallel and complementary efforts of both the Executive and Legislative Branches of the Federal Government to reduce the risks of life and property from future earthquakes in the United States. The Act called for the establishment of the National Earthquake Hazards Reduction Program (NEHRP) and the implementation of policies that underpin seismic hazard zonation mapping.

The mandated policies in the Act that underpin seismic hazard zonation mapping required consideration of both the occurrence and consequences of earthquakes. They include:

- Research into the basic causes and mechanisms of earthquakes.
- Development of methods to predict the time, place, and magnitude of future earthquakes.

- Development of information and guidelines for zoning land in light of seismic risk in all parts of the United States and preparation of seismic risk analyses useful for emergency planning and community preparedness.
- Undertaking studies of foreign experience with all aspects of earthquakes.
- Development of ways for state, county, local and regional governments to use existing and developing knowledge about the regional and local variations of seismic risk in making their land use decisions.

The National Earthquake Program (NEP), announced on May 20, 1996 by the President's Science Advisor, which will supersede NEHRP, continues the policy for:

- Development of seismic hazard and risk assessment tools, including seismic zonation studies.

II. Background

Ground shaking , (i.e., the amplitude, frequency composition, duration, and energy content of ground acceleration, ground, velocity, and ground displacement) is the dominant earthquake hazard that causes loss of life and societal impacts stemming from collapse, damage, and loss of function of structures. Ground shaking can be enhanced by site amplification (i.e., the frequency-dependent effects related to the thickness, geometry, and shear wave velocity of the near surface soil and rock underlying a construction site). Ground shaking is the principal causative factor in triggering ground failure (i.e., landslides, liquefaction, and lateral spreading).

The ground shaking hazard has been mapped probabilistically on national and regional scales since the mid 1970's (Algermissen and Perkins, 1976, Algermissen and others, 1982, Algermissen and others, 1990, Leyendecker and others, 1995) and in some cases on urban scales (i.e., 1:24,000 or larger) in cooperation with state geological surveys for portions of some states. At present, mapping for use in the 1997 Edition of the NEHRP Provisions is nearing the balloting stage.

The principal end users of the national and regional scale ground shaking hazard maps are Federal and state agencies concerned with regulations for new buildings, rehabilitation of existing buildings, standards for siting and design of lifelines, risk assessments, loss estimates, mitigation and preparedness. Model building code groups (e.g., National Building Code, Standard Building Code, Uniform Building Code, and the NEHRP Provisions) and associated professional groups such as Building Seismic Safety Council and American Society of Civil Engineers represent another important user group. The ultimate end users are the mega-cities, cities, and communities in all 50 states which are concerned with building regulations, land use zoning, and mitigation measures as they add new buildings and infrastructure to an existing inventory of structures that are vulnerable to the ground shaking hazard. These users also need urban scale maps (i.e., 1:24,000 or larger) to facilitate the planning process.

Other earthquake hazards that are mapped or analyzed in a comprehensive hazard and risk assessment and seismic zonation include: surface fault rupture, tectonic deformation, flood wave runup from tsunamis and seiches, and aftershocks.

The nation's earthquake prone areas have been delineated on the basis of geologic mapping, historic and current seismicity, paleoseismicity, and geodetic measurements. They include:

1. A transform plate boundary, marked by the 1,000 km-long (600 miles) San Andreas fault system in California, where earthquakes of .maximum magnitude ($M>8$) are expected. The state-of-knowledge is very good as to location and the probability of occurrence of future earthquakes and the nature of the consequences;
2. Plate boundary subduction zones, such as: a) in the Aleutian Islands, Alaska, where the Pacific plate is slowly being subducted beneath the North American plate and earthquakes of $M> 9$ are expected, b) the Pacific Northwest (i.e., Washington and Oregon) where the Juan de Fuca and North American plates are converging with the Juan de Fuca plate slowly being subducted beneath the North American plate and earthquakes of $M>8$ are expected, and c) in the Caribbean near Puerto Rico and the Virgin Islands where the Caribbean plate is slowly being subducted beneath the North American plate and earthquakes of $M>7.5$ are expected. The state-of-knowledge is rapidly improving in the first and second areas, but is relatively poor in the third area as to the probability of occurrence and the nature of the consequences.
3. A zone of crustal stretching and thinning, an intracontinental rift zone depicted by the New Madrid seismic zone in the Central Mississippi River valley where earthquakes of maximum magnitude ($M>8$) are expected. The state-of-knowledge is poor as to location and the probability of occurrence and the nature of the consequences.
4. The western basin and range province encompassing parts of Nevada and Utah which is characterized by young, active faults (such as the Wasatch fault system) and crustal deformation where earthquakes of maximum magnitude ($7.5<M<8$) are expected. The state-of-knowledge is good as to location and the probability of occurrence and the nature of the consequences.
5. Intraplate earthquake zones in the stable plate interior, such as in the Wabash valley (Indiana) where large-magnitude prehistoric earthquakes have occurred and earthquakes of maximum magnitude ($6.5<M<7.5$) are expected. The state-of-knowledge is very poor as to location and the probability of occurrence and the nature of the consequences.
6. The Atlantic continental margin and coastal zone, such as in the New England area where the Cape Ann earthquake occurred in 1755 and earthquakes of maximum magnitude $M=6.5$ are expected, and the Charleston, SC area where a very large earthquake occurred in 1886 and earthquakes of maximum magnitude M 7.5 are expected. The state-of-knowledge is very poor as to location, and the probability of occurrence and the nature of the consequences.
7. Hot spots beneath Hawaii and Yellowstone National Park (Wyoming) where earthquakes of .maximum magnitude ($7.0<M<7.8$) are expected. The state-of-knowledge is good as to location, but poor as to the probability of occurrence and the nature of the consequences.

III.. Implementation

Mapping is implemented through cooperative projects involving USGS's professional staff and experts in academia, the private sector, and state geological surveys. the latter working through external grants. The maps are based on integrated geologic, geophysical, seismological, geodetic, strong motion seismology, and geotechnical data, derived from ongoing research and the results of worldwide postearthquake investigations. They incorporate data on critical physical parameters such as the following:

- The characteristics of the active faults or seismogenic structures,
- The locations, focal depths, and magnitudes of historic and recent earthquakes,
- The frequency of moderate-, large-, and great-magnitude earthquakes (i.e., having magnitudes of 5.5 and greater),
- The earthquake's proximity to a community and its residences, buildings, and infrastructure,
- The signature of the earthquake source, path, and local site, as indicated by seismicity arrays and strong motion accelerograph instruments,
- The physical properties of the earth through which the seismic waves propagate and decay with distance from the source,
- The physical properties of the local ground and soil which can increase ground shaking in selected period bands and/or undergo permanent deformation,
- The existence and effectiveness of land use and building regulations to reduce the vulnerability of buildings and infrastructure to strong ground shaking and permanent ground displacements.

The calculations for the national maps, which express the earthquake ground shaking hazard as a probability of exceeding a specific measure of ground motion in a specific time period, are performed for more than 150,000 points throughout the Nation. At present, the maps depict either a 2 % or a 10 % probability of exceedance in an exposure time of 50 years for peak ground acceleration, peak ground velocity, and spectral acceleration (the 0.3 and 1.0 second ordinates) and a reference soil or rock.

The Building Seismic Safety Council (BSSC) has been involved in the implementation of the national ground shaking hazard maps for model building codes and the evolution of a "Design Values Map" based on and derived from them through the NEHRP Provisions since 1985 (Building Seismic Safety Council, 1986, 1995). The NEHRP Provisions, which are updated every three years, are developed through a consensus process involving several hundred individuals and organizations.

IV. Proposals

We have identified the following areas for potential joint projects between United States and Japanese participants:

1. Quantifying Future Earthquake Potential through detailed holistic study of the near source motions, geologic effects, and structural response. Ground shaking hazard maps can be improved in Japan and the United States by studying the total system in detail, including near source motions and geologic effects (i.e., the hazard environment), and structural response (i.e., the built environment), and incorporating this new knowledge into mapping methodologies. Near the causative fault, source directivity, breakout phases from surface fault rupture, and the "fling" of the fault may be important considerations that are not presently incorporated in ground shaking hazard maps.

2. *Reducing Earthquake Damage through performance based design methods that reflect more accurate ground shaking hazard maps..* Performance based design methods are imprecise without precise ground shaking hazard maps. The new ground shaking hazard maps in the United States are based on a new methodology which does not use the concept of seismic source zones, but instead depends on the slip rates of Holocene faults and the geographic distribution of historical earthquakes. To mitigate earthquake losses, we need to know how to map the ground shaking hazard with more precision than at present. Maps which describes the geographic change of the ground shaking hazard in terms of the probability of the exceedance of a fixed ground motion level may constitute a better tool for decisionmaking in the context of mitigation than maps that describe the variation in terms of the geographical variation of ground motion for a fixed probability level. It is clear that better ground shaking hazard maps will lead to more cost effective applications for reducing damage from earthquakes on national, regional, and urban scales.

3. Improving Information Systems for Probabilistic Ground Shaking Hazard Mapping through development of seismic information systems from postearthquake investigations. Ground shaking hazard maps frequently change after eathquake disasters. By working together, we can accelerate learning from earthquake disasters and determine and share the lessons on ground shaking hazzard mapping taught by earthquakes worldwide.

V. Cooperative Mechanisms

These proposals can be addressed successfully by collaboration under four of the proposed cooperative mechanisms. They are: a) the US-Japan Earthquake Disaster Mitigation Partnership organized in cooperation with the Japan Science and Technology Agency under the Common Agenda in Global Perspective, b) the UJNR, c) the JUST, and d) in part through the proposed Consortium of US and Japan Universities for Research in Earthquake Engineering.

VI. Additional Issues

During the current development of new national probabilistic ground shaking hazard maps for the 1997 Edition of the NEHRP Provisions, several scientific and technical issues requiring additional research have emerged. They include:

1. The new maps depict more accurately than before the recently recognized hazard from subduction earthquakes in the Pacific Northwest. The level of peak ground motion from a large magnitude subduction earthquake in the Pacific Northwest is expected to be relatively low for major cities, but the duration of shaking is expected to be relatively long, possibly causing severe damage to vulnerable older structures. In high-rise buildings, even if there is not severe structural damage, the combination of long duration of shaking and the amplitude of the building response may damage equipment, disrupt contents, and cause psychological distress to occupants.
2. We need good slip rate information for faults. especially for recognized Holocene faults which have not been dated either by trenching or reconnaissance geomorphology. In those cases where fault recurrence relations are found to be long. consideration should be given for ensuring that design ground motions are more protective than the somewhat lower levels shown on the 2 % and 10 % in 50-years probabilistic maps.
3. Studies of the uncertainties in the ground motion values on the new maps have just begun. Initial studies suggest coefficients of variation between 0.2 and 0.4, with the larger values being those calculated near faults where source directivity, breakout phases from surface fault rupture, and the "fling" of the fault may be an important consideration, or in the vicinity of poorly-understood seismic sources. Design applications should incorporate this variance in uncertainty into account during the design process.
4. The new maps display ground motion in terms of the geographical variation of ground motion for a fixed probability level, which is useful in terms of seismic design in building codes. However, in some applications, these maps may not be the most useful way to present the hazard. For example, for insurance underwriting and mitigation purposes, consider that many buildings can be characterized by a ground motion fragility threshold, below which damage may be negligible and above which damage may be considerable. Maps which describes the geographic change in terms of the probability of the exceedance of that fixed ground motion level may constitute a better tool for decisionmaking in these contexts.
5. In some parts of the Nation, the new ground motion values may be considerably higher than formerly recognized. The economic, political and legal implications of these changes need to be examined.
6. Working in cooperation with BSSC committees, the USGS is developing "Design Value Maps" from the new probabilistic ground shaking hazard maps. This process calls for incorporating "floor" provisions for minimum standards where the probabilistic hazard values are low, plateaus where probabilistic hazard values exceed current maximum design requirements, and higher, deterministic, median ground motion values in the vicinity of faults, where these values exceed the plateau values. The economic, political and legal implications need to be examined for a wide class of buildings and hazard environments.
7. The new ground shaking hazard maps are based on a new methodology which does not use the concept of seismic source zones, but instead depends on the slip rates of Holocene faults and the geographic distribution of historical earthquakes. In this new methodology, the following factors are more important than in the older source-zone methodology: a) the

accuracy of the magnitudes and locations. b) the conversion of various historical intensities and magnitudes to a common modern magnitude suitable for use with modern attenuation functions, and c) the size and functional form of the geographical smoothing parameter. The sensitivity of map values to these factors needs to be examined.

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